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THE APPLICATION OF SYSTEM DYNAMICS TECHNIQUES
TO WAR GAME MODELING

Mr. G. Vincent Amico

ABSTRACT

Military War Gaming has developed from the chess-like games to the elaborate computer simulations of today, using high-speed, general-purpose, digital computers. This Research Report will briefly review modern war-game developments with emphasis on real-time training systems. The application of system dynamics techniques developed by Jay W. Forrester to war-game modeling is explored. A simple destroyer versus submarine model is developed. Results indicate that the system dynamics modeling technique is a powerful and effective tool. However, the Dynamo language could be substantially improved by a more powerful logical statement capability.

THE APPLICATION OF SYSTEM DYNAMICS TECHNIQUES
TO WAR GAME MODELING

BY

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B. of A.E., New York University, 1941
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RESEARCH REPORT

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for the degree of Master of Science in Engineering
in the Graduate Studies Program of
Florida Technological University, 1973

Orlando, Florida

PREFACE

The use of war gaming as a technique for training military officers has experienced varying degrees of emphasis through the years. The growth in the complexity of the war game has essentially paralleled the development in the materiel of warfare. The introduction of economic, large-scale computing systems and the development of high-level, user-oriented languages now permits the application of these advances in technology to the real-time, interactive, war-game-oriented training device. With the computing system technology available, the application of ~~system dynamics techniques of studying the dynamics of~~ combat as a closed-loop information feedback system became very attractive to me, especially after 25 years of involvement in the development of training devices. This position is further supported by the current interest in war gaming devices within the Army and the Navy.

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CHAPTER I

INTRODUCTION

In recent years both military and scientific experts have used a variety of techniques to assist in finding solutions to the difficult problems that face military decision makers (reference 1). The increasingly complex military decision making process can be attributed to the increased speed of vehicles and the complexity of modern weapons, the variety of sensors which are used to detect and localize the opponent, and, finally, the computer complex which is used to process and evaluate sensor data and indicate tactical alternatives to the commander of tactical units in a matter of seconds. Although the military decision maker has many aids available to him, the final decision still rests with him. The inability of the military professionals to practice these complex skills in time of peace leads to the development of war gaming (reference 2).

In this research report the historical development of war gaming will be briefly traced. The war-gaming systems principally oriented to train military officers will be

reviewed. The relationship between the laboratory simulation studies and the rigorous concept of the theory of games to the training-oriented war gaming will be investigated. Finally, the application of system dynamics concepts to war-game modeling will be developed. A simplified model will be implemented by means of a Dynamo program to demonstrate feasibility.

The premise that war gaming is in reality a continuous dynamic system with information feedback and decision making will extend the modeling techniques which Forrester developed for industrial, urban, and world dynamics, to include their use for war gaming (reference 3).

CHAPTER II

HISTORY OF WAR GAMING

Modern war gaming has evolved along with the development of game theory operations research and high-speed digital computers. The developments of the early nineteenth century will be briefly traced through current war-game activities. It is not surprising to find that progress in the evolution of war gaming was slow through the nineteenth and first half of the twentieth centuries. The war-gaming techniques expanded along with the burgeoning technologies of the second half of the twentieth century.

Early Developments

The modern concept of war gaming is attributed to von Reisswitz Jr. In 1824 von Reisswitz introduced map-like charts and adapted the game to actual military operations (reference 4). Prior to that time war gaming retained many of the features of chess and, later, of war chess, which is the foundation of modern war gaming. Although von Reisswitz's game was initially received with enthusiasm, it did not retain its initial popularity. The game required numerous and special rules. As a result the

game was complicated and time consuming (reference 4). The next major advance in war-game technology took place in 1876 when Colonel von Verdy de Vernois called for a free conduct of the game based on modern strategy and tactics. As a result of this simplification, the war game became one of the principal methods of teaching military tactics (reference 4). This led to the classification of war games into rigid or free Kriegspiel. Games played with a specific set of rules were called "Rigid Kriegspiel," while games in which the umpire had greater flexibility in judging the effect of actions (such as gun fire), based upon his experience, were called "Free Kriegspiel."

Major W. R. Livermore of the U. S. Army Corps of Engineers made a major contribution to war gaming. The war game he developed was based primarily on the work of von Tschischwitz (reference 4). Major Livermore identifies some of the principal variables in the land-combat war game. He developed standards for variables, such as casualty rates, troop movement, and fire rates. The factors which influence these rates, such as the firing range, terrain features, and the circumstances influencing

rate of fire, were considered in Livermore's game. The outcomes of chance and probabilistic events were determined by the casting of dice. Livermore's game was considered in the Rigid Kriegspiel class (reference 4). Young (reference 4) quotes Sayre as saying in his book, Map Maneuvers and Tactical Rides:

" . . . Livermore's system is the best of its class, but it cannot be readily and intelligently used by anyone who is not a mathematician, and it requires, in order to be able to use it readily, an amount of special instruction, study, and practice about equivalent to that necessary to acquire a speaking knowledge of a foreign language."

In the last edition of his book (reference 5), Livermore himself recognized the effect of excessive and time-consuming computation in the conduct of the game.

As early as 1886, Lieutenant William McCarty Little suggested a game called the "Naval War Game." The game employed blackboards and maps. Maps illustrated the ocean or coastal areas involved in the maneuvers. Miniature ships were utilized. Ship movement and the effects of firepower were determined by calculations. Little delivered a series of lectures on naval war gaming at the Naval War College in 1888 and 1889. However, the first

war-game training exercise involving students was not conducted at the Naval War College until 1894 (reference 2).

The Free Kriegspiel war game of the von Verdy type became popular in the early twentieth century. This trend was accompanied by the practice of using maps of actual terrain. Games of this type were developed by Eisenschmidt in 1903, Immanuel in 1907, and Sayre in 1908. Immanuel even accounted for the delay time for communications (reference 4).

~~The general techniques for conducting two-sided war~~ games, which have been previously described, was to have either two or three map rooms. Two of the rooms would have a map showing the disposition of one's own forces and of known opposition forces. If there was a third room, the umpire's room, the disposition of both forces would be shown. Commanders would then write their orders and pass them to the umpire. The umpire directed the movements made on the maps. The results of hostile contact were decided by the umpire, based on his judgment (reference 4). In the Rigid Kriegspiel games more

computation was required and probabilistic devices were used to determine the outcome of certain chance events.

Post World War I

In the period after World War I the war games were similar to those developed by von Verdy, except for updating based on new weapons and tactics (reference 4). There was no real improvement in the war games utilized for training at the Army's Command and General Staff College and the Naval War College during this period (reference 4).

~~The war game suggested by Lieutenant Colonel J. M. Milling, as cited by Young (reference 4), established three basic methods of conducting war games. These methods are:~~

1. Two distinct sides. Only information normally available to a Commander of each side is provided.
2. The actions of one Commander are regulated by an umpire. In effect, the umpire becomes the opposing Commander.
3. One side is a skeleton force. Actions are indicated to the other side through narration and fire direction.

These methods of operation were incorporated into the design of tactical and war-game training devices.

A mathematical approach to game theory was developed by von Neumann in 1927. Von Neumann described a conflict situation in which the consequence of the decision not only depends on the action of the decision maker but also on the opponent's action (reference 4). The decision rule is called the "Minimax Principle." Von Neumann and Morganstern published an extensive mathematical development of game theory (reference 6).

Modern War Gaming

In the past twenty years, high-speed digital computers have been used to derive the best decision to make in a given tactical situation, the best equipment and weapon system to use, and the best weapon characteristics to obtain for the future (reference 4). These computer run war games can be classified as models. These models are used to optimize strategy of tactics. In 1959 John P. Young stated (reference 4):

". . . The use of the model, combined with the extensive amount of statistical and mathematical data as input, demand

complex formulation by scientists and mathematicians together with the use of extensive computer systems."

The economic availability of powerful computer centers, along with the relative simplicity of programming through the use of high-level language in the post 1965 era, has had a significant impact on the ability of military tacticians and strategists to conduct war games for training or weapon/tactics effectiveness studies.

The Department of Defense and the individual military services have sponsored extensive studies in war gaming to assist in the development of new strategy and tactics or in the selection of performance requirements of new weapon system development. A summary of war-game modeling effort is contained in reference 7.

CHAPTER III

TRAINING DEVICE AND WAR GAMING

The war games which have been described generally consisted of one- or two-sided games, regulated by an umpire. Not unlike chess, a move was made by one side and a countermove made by the other side (or the umpire in the case of a one-sided game). Based on the action taken by a commander, the results were determined, sometimes by computation with or without chance, or sometimes by the judgment of the umpire on the forces of the opposition.

Basic Training Device Design

A training device involves the simulation of a strategic or tactical situation for decision-making training purposes. Command and control centers of a number of tactical units, e.g., ships, companies, etc., of a tactical commander are essentially duplicated. Information display devices, such as cathode ray tubes, status boards, weapon status information, and communication network data that normally would be available, would be provided.

Analog, hybrid, or digital computing systems would, through the solution of differential, algebraic, and logic equations, compute the position of vehicles, the ranges and bearings between vehicles, the ability of units to detect each other with the sensors available based on the conditions of the environment, and compute the trajectory and effect of weapon fire. Although the model which is mechanized in the computer system is by necessity linearized and simplified, the resultant problem dynamics are sufficiently valid to permit the conduct of effective training exercises (reference 8). The intrinsic advantage of these training device systems, as contrasted with the operations-research-oriented digital computer modeling, is that the normal human errors and delay factors in reading and interpreting data are randomly (realistically) introduced and a realistic decision-making process can take place.

War-Game Devices

One such system is the NEWS (Naval Electronic Warfare Simulator) (reference 9). This system was specifically developed for war gaming in support of the curriculum at the Naval War College.

Another such device was specifically developed to exercise the Anti-Submarine Warfare (ASW) carrier task force. The coordinated ASW Tactical Trainer, Device 14A6, was developed to train the key ASW combat team decision makers of aircraft, surface ships, and submarines, in a combined, multiplatform-coordinated, ASW tactical problem (reference 10).

The two previous examples describe training devices for naval warfare. Training devices have also been developed to exercise naval officers in amphibious assault tactics, especially the shore bombardment task associated with these operations. This system, the Amphibious Assault Trainer, Device 16B13, retains the map feature of the early war game but mechanizes the weapon trajectory and impact computation. A visible impact point is presented to the spotter and fire-control officer so that the necessary fire-control corrections can be made (reference 11).

Training devices for decision-making training in land-combat tactical operations have not been extensively developed. Training devices cover limited tactical exercises, such as the aerial-observer problems for

artillery spotting. Large, three-dimensional terrain maps are used for the problem. The shell impact point is simulated by ejecting a puff of smoke at the impact location through the map (reference 12).

War-Game Models

Computer games, such as Carmonette, have been formulated (reference 13). This game is essentially a mechanization of a "Rigid Kriegspiel" type war game, and is classified as a Monte Carlo type of game. Another such computer war game is Maneuver and Fire Analyzer (MAFTA) (reference 14). The possible reason for the limited development of Army tactical-type war-game training devices is the inherent difficulty of modeling the game because of the number of troops and mechanized units involved and the complexity of describing the infinite variety of terrain features involved in the problem. Another factor which has probably influenced the slow development of land-combat war-gaming devices is the difficulty of simulating the data inputs to the command decision process. In contrast, the surface ships information gathering system is relatively simple. Sensor

information from radar electromagnetic signal receivers (ECM), and sonar are displayed on cathode-ray tubes.

The display devices for these sensors are located in or adjacent to the combat information center. The infantry command post must rely heavily upon visual observation from either the ground or air. These observations are then transmitted by communication links to the command post for recording, plotting, and evaluation. The quality of the information is subject to many degrading variables, e.g., detection, position accuracy, human error in ~~information handling, and delays occasioned by each of~~ the sequential phases of the process.

Training Device Characteristics

The significant advantage of the training device designed and used for war-gaming training is that it allows the human elements to be introduced into the problem. The principal elements are those of error, delay, and decision making. The effect of the absence of combat stress in training devices has been investigated (reference 15). This limitation has been recognized. Another consideration, however, is that the training device may have a number of inherent disadvantages.

Simplification in the dynamic model mechanized in the computer may not represent the true limitations or capabilities of the operational systems they simulate.

Lack of detail information of the model itself and a study of its inherent characteristics may result in commanders attempting to achieve results beyond the basic capabilities of the system. In these areas the operations-research computer-model studies have a distinct advantage.

CHAPTER IV

COMBAT AS A DYNAMIC INFORMATION FEEDBACK SYSTEM

In a study sponsored by the Office of Naval Research with Computer Research Corporation of Newton, Massachusetts (reference 7), the following statement is made:

"These same techniques will help to reduce the gap which differentiates the model designer from the model user. Each group has different requirements and problems. The model designer tends to be more proficient in computer programming and operation; however, in general, he has less understanding of the national requirements and purposes for simulation and war gaming. Because his jargon and background is different from that of the model user, there may be some misunderstandings of the political and military realities to be modeled. At the same time model users who are not generally computer experts, may not appreciate the model designer's problem. The users don't always understand what can and cannot be done with a computer. Invariably they expect more than the model designer can deliver and, because of the communication barrier, the misunderstanding is not discovered until the model and its implementation in the form of a game or simulation is finally delivered."

The quotation above states the crux of the problem. If large-scale, high-speed computers are to have significant application to interactive computer war gaming for

training purposes, the task of modeling and programming must be simplified so that the tactician can actually become the model developer.

A summary of the computer languages which have been employed in various war-game applications, based on the data contained in the Catalog of War Gaming Models, dated January 3, 1966, is as follows: (reference 7)

<u>Program Language</u>	<u>Number of Models</u>
Fortran (all versions)	49
JOVIAL	12
LO (LL-1)	8
FAP	11
STRAP	6
Other	<u>6</u>
	92

These data indicate the extensive use of Fortran, over 50 percent, in war game programming. Fortran, although an effective language, cannot be considered to be user oriented.

With the advent of the high-level computer programming languages in the past five years, coupled with the significant reduction in the cost of computers (reference 16), it appears as though the communication gap between the programmer and the user can be significantly reduced.

With these objectives in mind, the applicability of techniques of system dynamics, together with the use of a Dynamo/CSMP type, user-oriented, high-level language, has considerable appeal.

Modeling and Computer Language Barrier

In all the literature which has been reviewed, there is only one indication that system dynamics techniques were considered for possible application to war gaming. The Dynamo Users Manual is cited in the bibliography of Computer Research Corporation Report R-102-4 of August 1966. No mention is made of Dynamo in the text (reference 7).

In order to advocate the use of a continuous dynamic systems concept to war-game modeling, it will be necessary to establish that a war game is in fact a continuous dynamic system with the essential ingredients of structure, delay, and gain (reference 3).

Warfare as a Dynamic System

The literature on the development of war games does identify war or combat as a dynamic system (reference 1). However, the time-varying, continuous, information feedback,

closed-loop aspects of the system are not extensively explored. Games are described as decision making with probabilistic outcome based on that decision. Clayton J. Thomas states that the concept of dynamics was introduced by Lanchester in 1916 when he investigated mathematics in warfare (reference 1). Lanchester developed the following differential equations:

$$\frac{db}{dt} = -r \times c$$

$$\text{Error.} \rightarrow dr = -b \times k$$

b = Blue Forces

r = Red Forces

c = constant (fighting value)

k = constant (fighting value)

These simplified, first-order, ordinary differential equations determine the casualty rate and resultant strength as a function of time based on the fighting value of each force. Such a set of equations has a closed-form solution. In their bibliography (reference 17), Riley and Young cited a number of reports and papers which extend the early work of Lanchester.

A model of a combat situation can be developed based on the system dynamics concept to encompass all aspects of the problem. For example, in an air defense situation where enemy bombers are attacking a military target, the following word statement of the time-varying differential equations would be involved:

Bomber Position - Function of speed, heading

Bomber Altitude - Function of climb/dive rate

Bomber Fuel - Function of speed, weight, altitude

Bomber Defensive Weapons - Type, fire rate, hit

probability

Bomber Oxygen - Altitude

Interceptor Position - Function of speed, heading

Interceptor Altitude - Function of climb/dive rate

Interceptor Fuel - Function of speed, weight, altitude

Interceptor Oxygen - Altitude

Interceptor Weapon - Type, fire rate, hit probability

If the interceptor is in a given alert condition until an unidentified target is detected by the early warning radar system, the following events are typical of what may take place:

1. Detect target - 50% probability of detection at a specific range
2. Classify target - decision delay
3. Classified unidentified
4. Issue alert - decision delay
5. Interceptor airborne - delay
6. Vector interceptor - delay
7. Close target-structure (dynamics)
8. Acquire target on airborne fire-control radar - delay
- ~~9. Close to firing range-structure (dynamics)~~
10. a. Bomber fires weapons-decision (hit-probabilistic)
- b. Interceptor fires weapons-decision (hit-probabilistic)

Although the description presented above is by no means complete, it does provide the information which is considered necessary to substantiate that a combat situation contains the elements common to any industrial or social system. The elements are:

1. Structure of system
2. Delays
3. Gains
4. Decisions

The appeal of the system dynamics approach to problem identification and analysis is that the initial phase, namely the word description, is in terms of the user and his vocabulary. In addition, the conversion of the word description into a system flow diagram is still in the language of the user.

~~The discipline which these first two steps force in~~
the development of a computer model result in a better understanding of the combat situation and insure a more valid and useful model. On the other hand the omission of an essential parameter is dramatically demonstrated when the results of the first computer run are analyzed.

The foregoing discussion has alluded to the premise that there may be more training value to be obtained from the development of the model through the preparation of word descriptions and diagrams than there would be in conducting training exercises in tactical or strategic

decision-making situations with models of systems with which they are not familiar. This supposition has not been proven but may be worthy of further investigation.

CHAPTER V

WAR GAME MODELING USING SYSTEM DYNAMICS

System Dynamics Technique

The development of a system dynamics model as set forth by Jay A. Forrester (reference 3) consists of the following steps:

"Identify Problem.

Isolate the factors that appear to interact to create the observed symptoms.

Trace the cause and effect information - feedback loops that link decisions to resulting information changes and to new decisions.

Formulate acceptable formal decision policies that describe how decisions result from available information streams.

Construct a mathematical model of decisions, policies, information sources and interaction of the system components.

Generate the behavior through time of the system as described by the model (usually with a digital computer) to execute the lengthy calculations.

Compare results against all pertinent available knowledge about the actual system.

Revise the model until it is acceptable as a representation of the actual system

Redesign, within the model, the organizational relationships and policies which can be altered

in the actual system to find the changes which improve system behavior.

Alter the real system in the direction that model experimentation has shown will lead to improved performance."

Forrester also states,

"The first and most important foundation for industrial dynamics is the concept of servo-mechanisms (or information-feedback systems). . . ."

He then defines an information feedback system as,

"An information feedback system exists whenever the environment leads to a decision that results in action which affects the environment and thereby influences future decisions."

The procedure outlined by Forrester is equally applicable to the study of combat through war gaming. There is one additional capability which should be included into the system. This capability would enable decisions to be made by the responsible commander interactively with the model, rather than by including the decision model in the program.

In order to demonstrate the applicability and the effectiveness of using the System Dynamics technique and the Dynamo computer language, a simplified naval tactical exercise will be described, diagrammed, programmed, and run on a computer. The results will be assessed for validity of the system dynamics approach to war gaming or

combat simulation.

Tactical Problem

The tactical problem which will be developed consists of one transiting submarine and a single destroyer. The objective of the destroyer is to deny the submarine access to a given area. It might be argued that the situation as stated is overly simplified and that many additional factors would influence the problem. This argument is valid and cannot be denied. However, for purposes of demonstrating techniques of the method the situation as stated is considered adequate.

The formulation of the system to be modeled will be broken down into major subdivisions. The subdivisions of the tactical problem are:

1. Vehicle motion
2. Relative position
3. Detection
4. Attack
5. Damage assessment

Each subsystem model will be developed and related to the system flow diagram.

The tactical environment is depicted in Figure 1. The

TACTICAL ENVIRONMENT

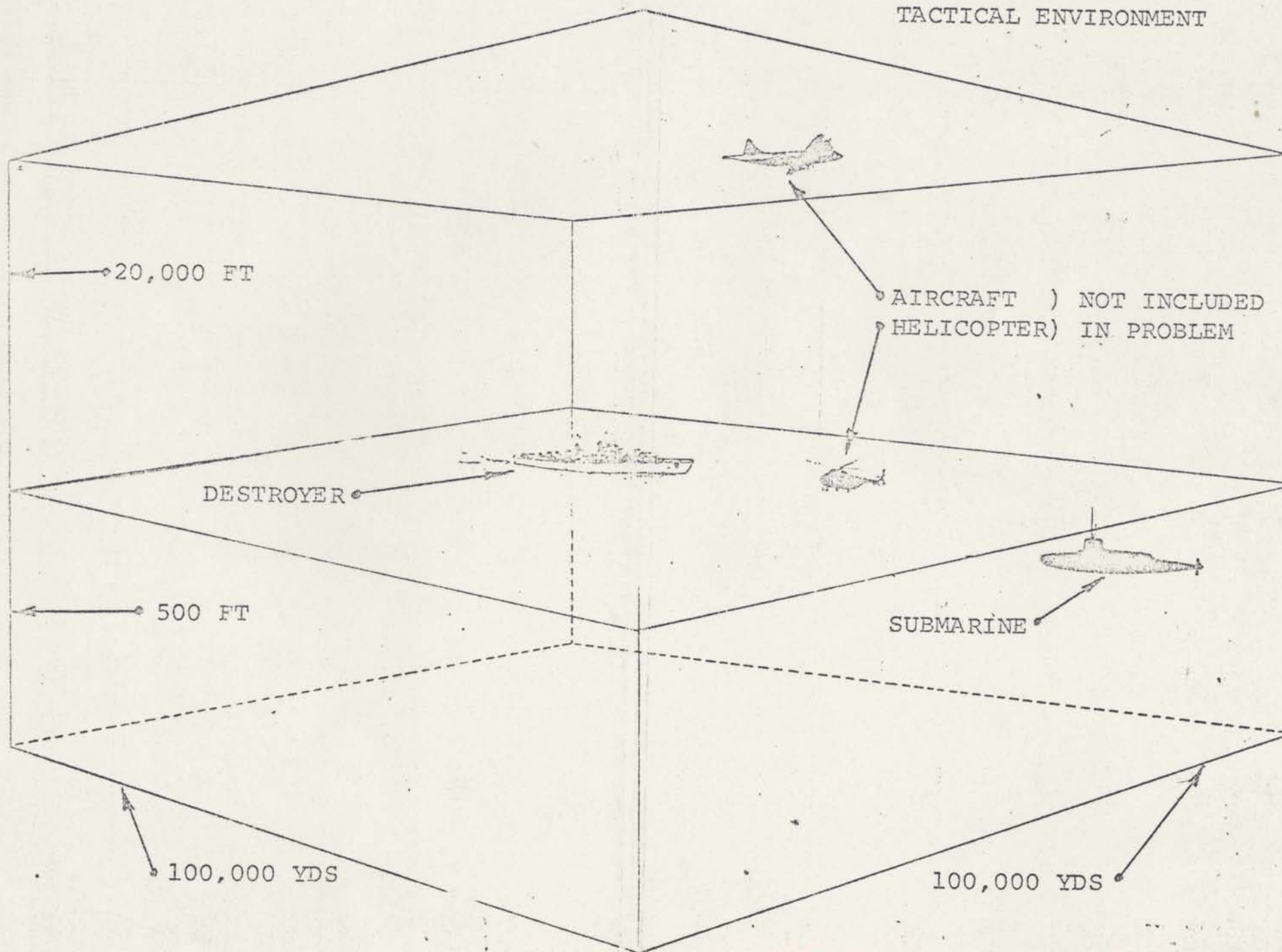


FIGURE 1

game area is defined, and the submarine depth limit is defined. There are a number of environmental factors which affect the conduct of the problem. These factors include:

1. Precipitation/humidity/cloud cover
2. Visibility
3. Wind speed and direction
4. Sea state (wave height)
5. Ocean sound velocity profile
6. Ocean depth/bottom characteristics
7. Ocean current
- ~~8. Ambient acoustic shipping noise~~
9. Marine-life acoustic noise

These environmental factors influence, directly or indirectly, the movement of vehicles and the performance of the various sensors. For the problem which is being developed these factors will be considered only indirectly in the establishment of the radar and sonar detection ranges.

Vehicle Motion

The motion model consists of two basic elements: true heading or vehicle course in degrees from true north, and speed in yards per minute. If the vehicle is capable of motion in the Z axis, an altitude or depth calculation is

also required.

In the flow diagram, Figure 2, VH1 represents the heading of vehicle 1. Vehicle heading is changed as the result of ordered heading changes or heading to the target submarine in the event a contact is made, A3VH1. The turn rate, A5VH1, used as the input to the heading is based on the heading error, A4VH1. The terms A1VH1 and A2VH2 are used to keep the heading within the 0° to 360° limits. The turn rate input to the heading equation as a function of the heading error is shown in Figure 3.

The vehicle speed flow diagram is shown in Figure 4. The speed of the vehicle 1, VS1, is determined by comparing the ordered speed, A3VS1, with the actual speed, VS1. The speed error, delayed by the vehicle time constant, VDELL1, becomes the speed change rate, VSRL1. The speed ordered for the vehicle is normally based on the time function, OSV1. In the event that the submarine is detected as determined by DR12, the destroyer will be ordered to proceed at VMAX to the target.

In the case of the submarine, it is necessary to compute depth. In addition, the percent charge on the submarine battery constrains the ability of the submarine

HEADING FLOW DIAGRAM

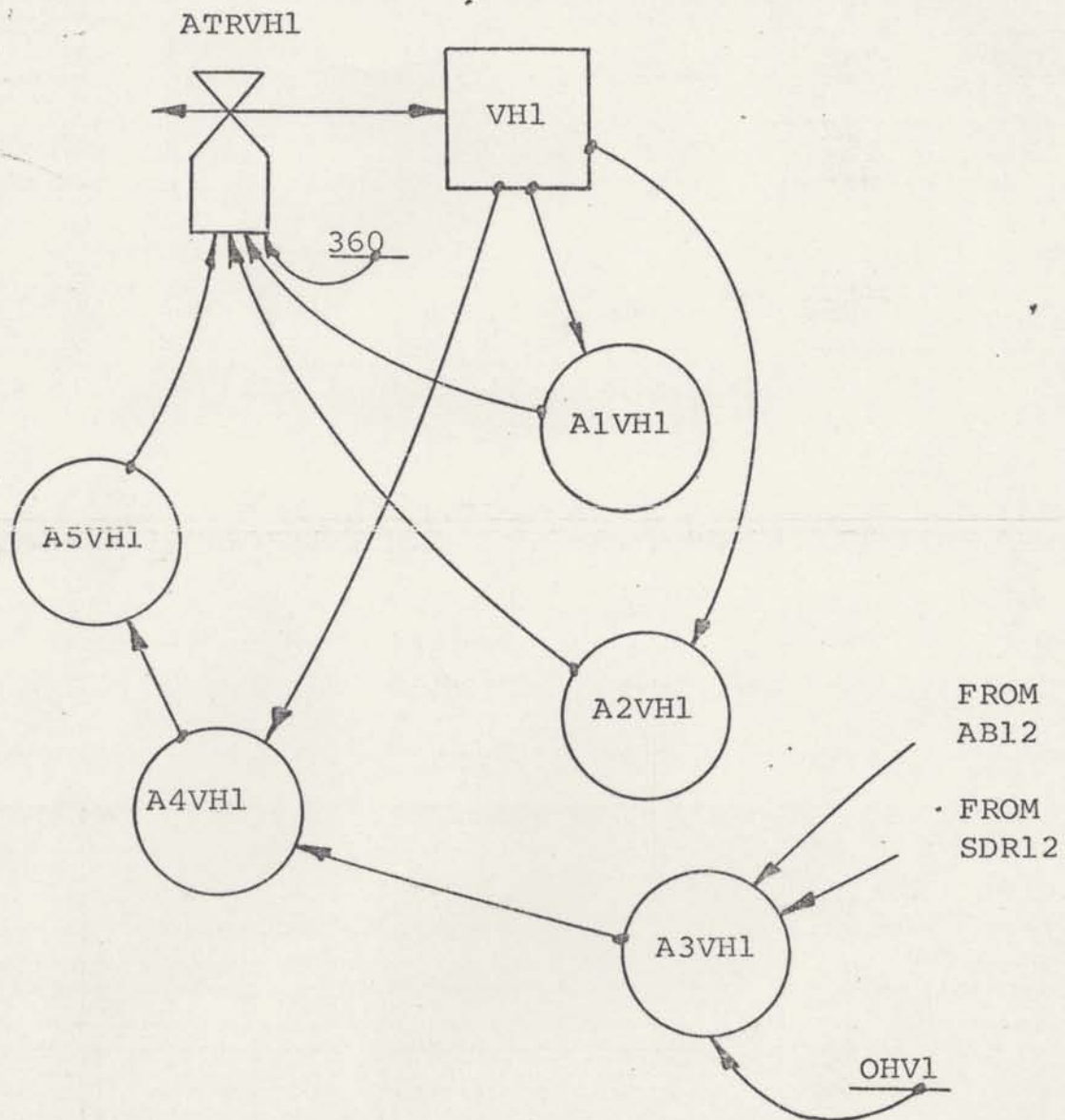


FIGURE 2

TURN RATE FUNCTION

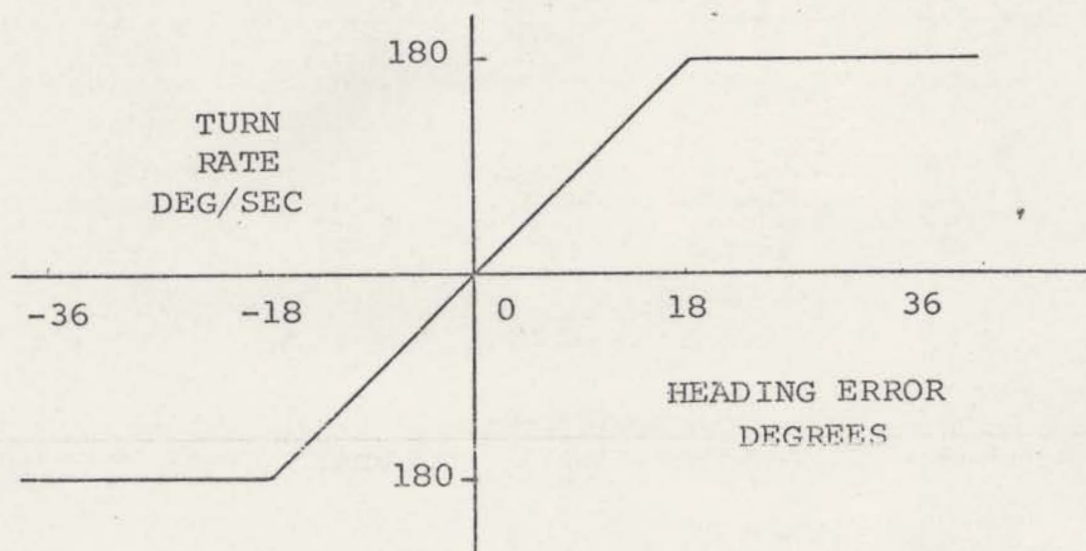


FIGURE 3

SPEED FLOW DIAGRAM

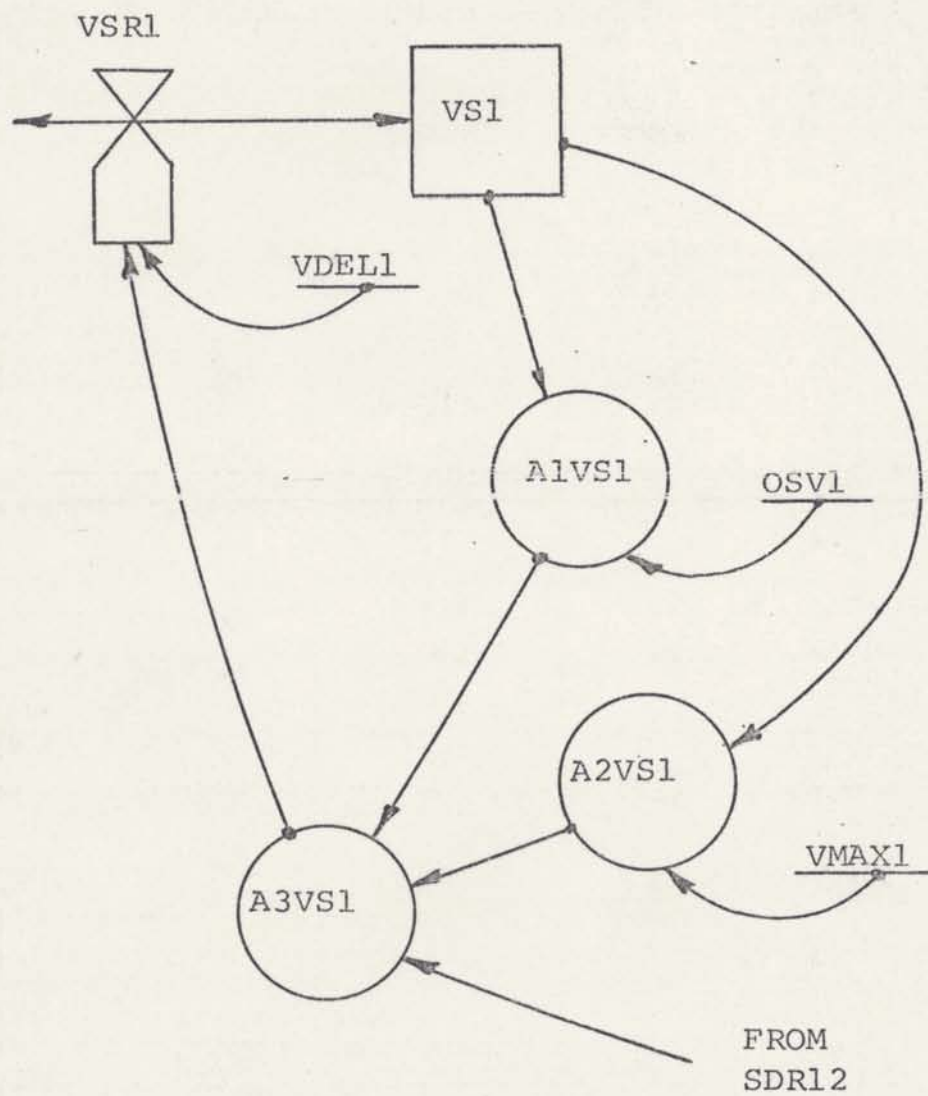


FIGURE 4

to submerge under certain conditions. The flow diagram for submarine depth and battery condition is shown in Figure 5.

Submarine depth is normally determined by the ordered depth function unless the battery charge falls below 20 percent. The ordered depth selection is established in A1Z2. Based on ordered depth, A2Z2, the climb or dive rate is determined by A3Z2 and introduced into VZR2. The climb-dive rate as a function of depth error is shown in Figure 6.

The condition of the battery charge is VC2. The charge rate, VCR1N2, is fixed but the submarine must be snorkling or surfaced, A2VC2. Charging is terminated when the charge is at the .95 level, A3VC2. The battery discharge rate, VCROT2, is a function of submerged speed, A4VC2 and A5VC2. The battery discharge rate as a function of speed is shown in Figure 7.

Relative Motion

The relative motion computation consists of two phases. First, the differences between the respective X and Y position of two vehicles must be determined. Then the range and bearing of the vehicles with respect to each

SUBMARINE DEPTH AND BATTERY FLOW DIAGRAM

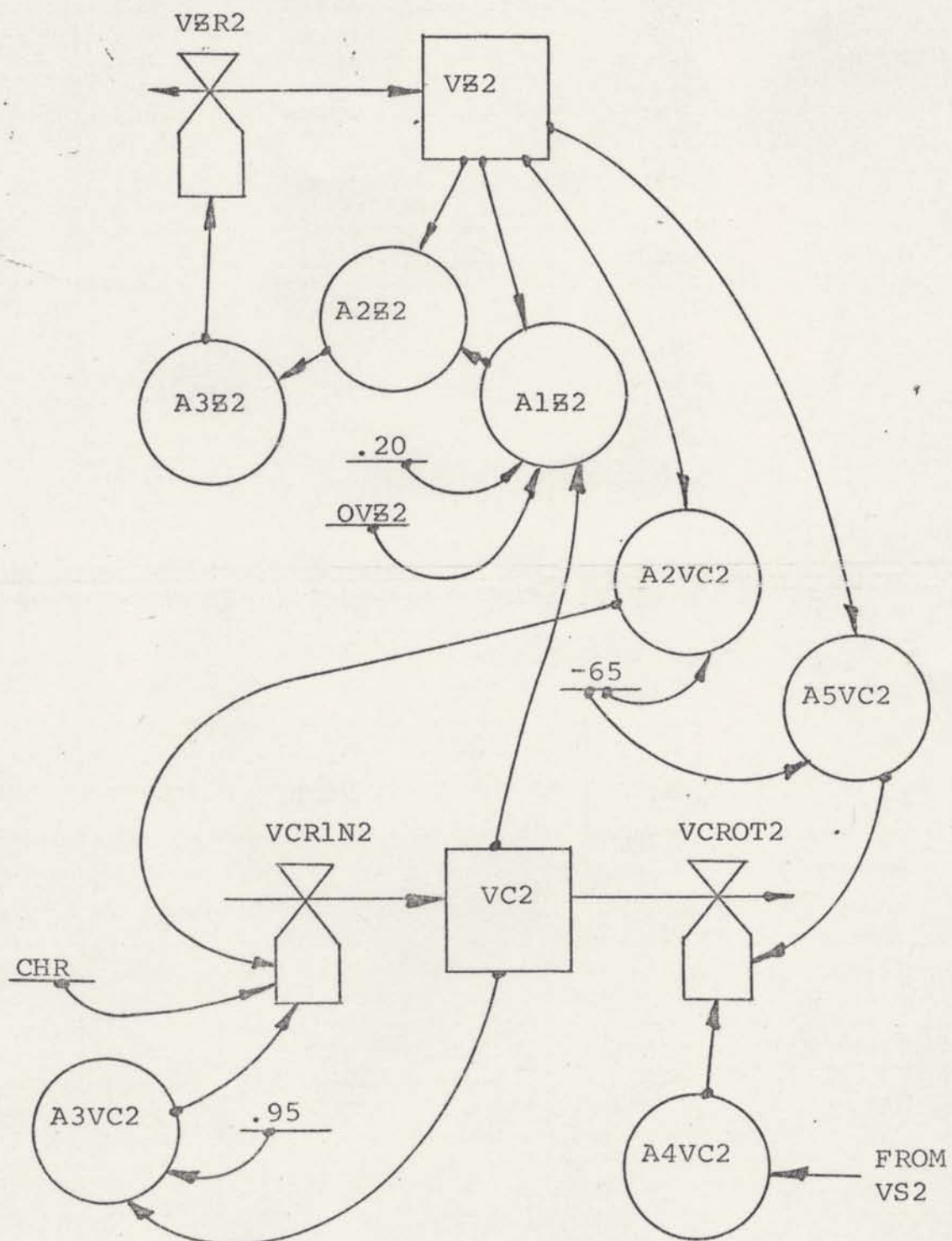


FIGURE 5

DEPTH RATE FUNCTION

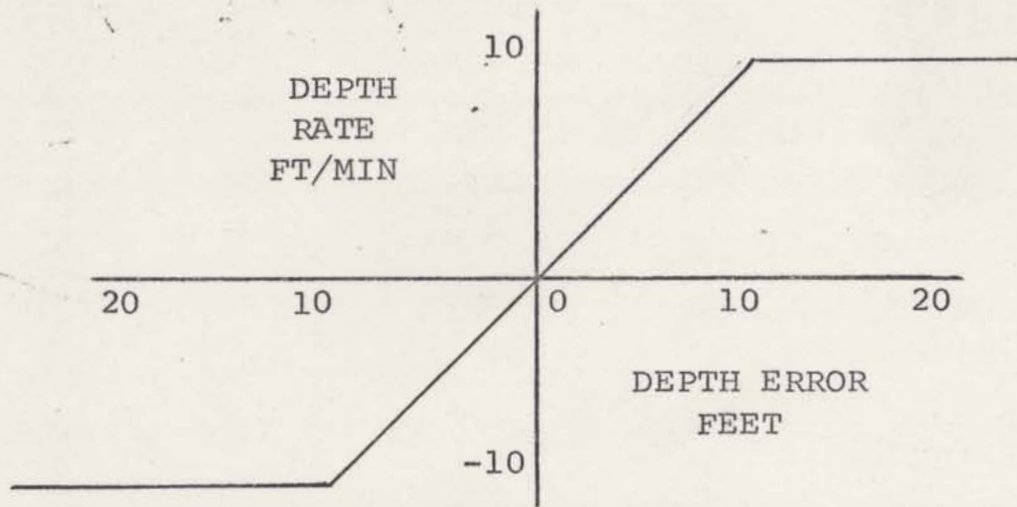


FIGURE 6

BATTERY DISCHARGE FUNCTION

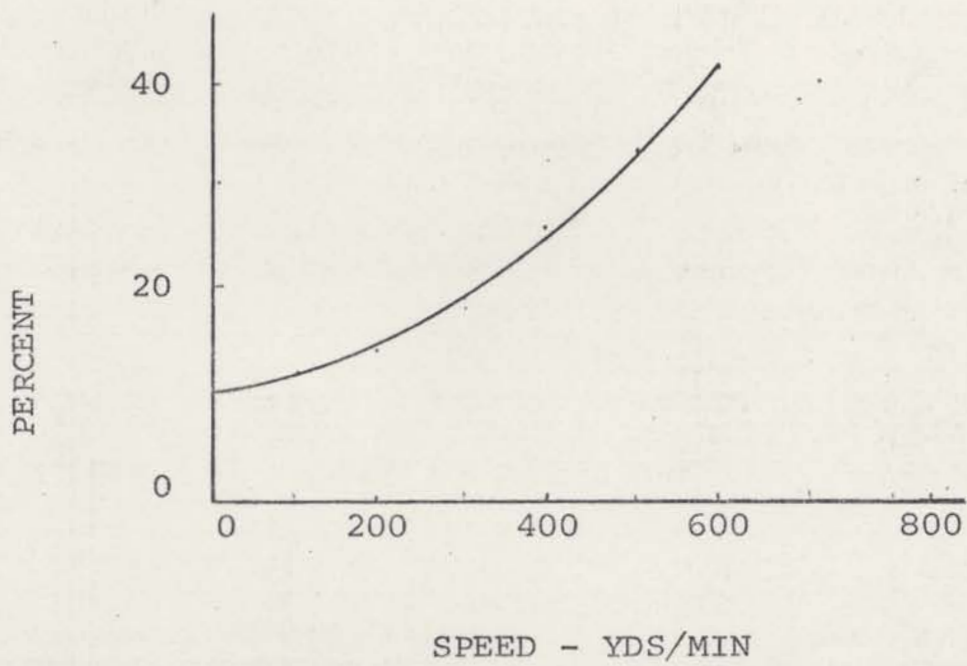


FIGURE 7

other must be calculated. The relative motion flow diagram is shown in Figure 8.

The speed of each vehicle, VS1 and VS2, is resolved into X and Y components VX1 and VY1, based on vehicle heading, VH1. These components are integrated into X and Y positions, XS1 and YS1.

The X and Y position of one vehicle is then subtracted from the X and Y position of the other vehicle to obtain ΔX and ΔY , AX12 and AY12. Then range between vehicles, AR12, is determined by the relation

$$AR12 = \sqrt{(AX12)^2 + (AY12)^2}$$

The true bearing of the submarine from the destroyer is obtained by taking the inverse of

$$ARCSIN = \Delta X/R$$

Since Dynamo has no intrinsic arcsin function, an inverse function AB12 was developed.

Target Detection

The flow diagram, Figure 9, for simplified target detection model uses fixed detection ranges for the radar and sonar sensors. Radar detection is established if the submarine is snorkling or surfaced, VS2, and within 20,000

RELATIVE POSITION FLOW DIAGRAM

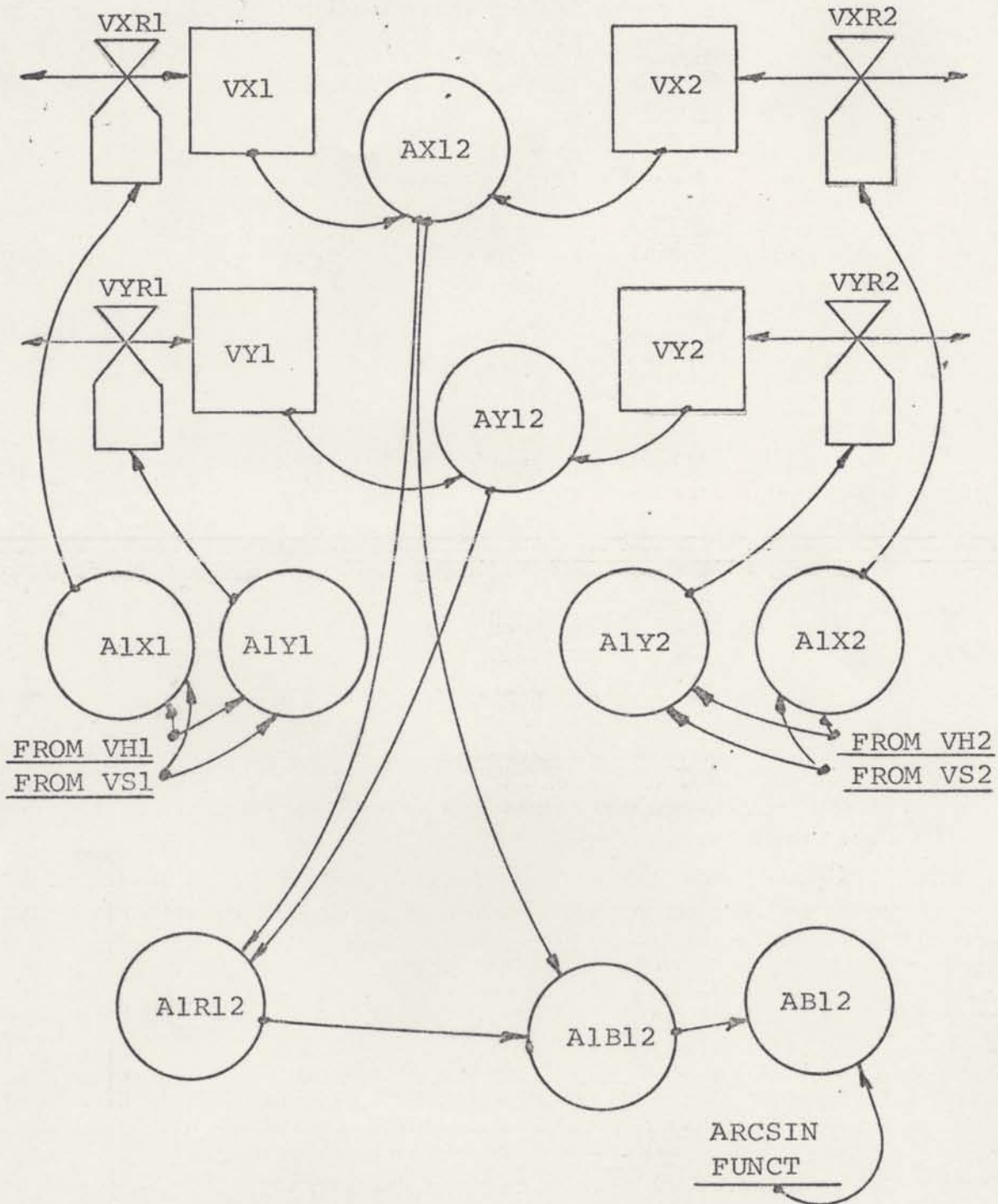


FIGURE 8

TARGET DETECTION FLOW DIAGRAM

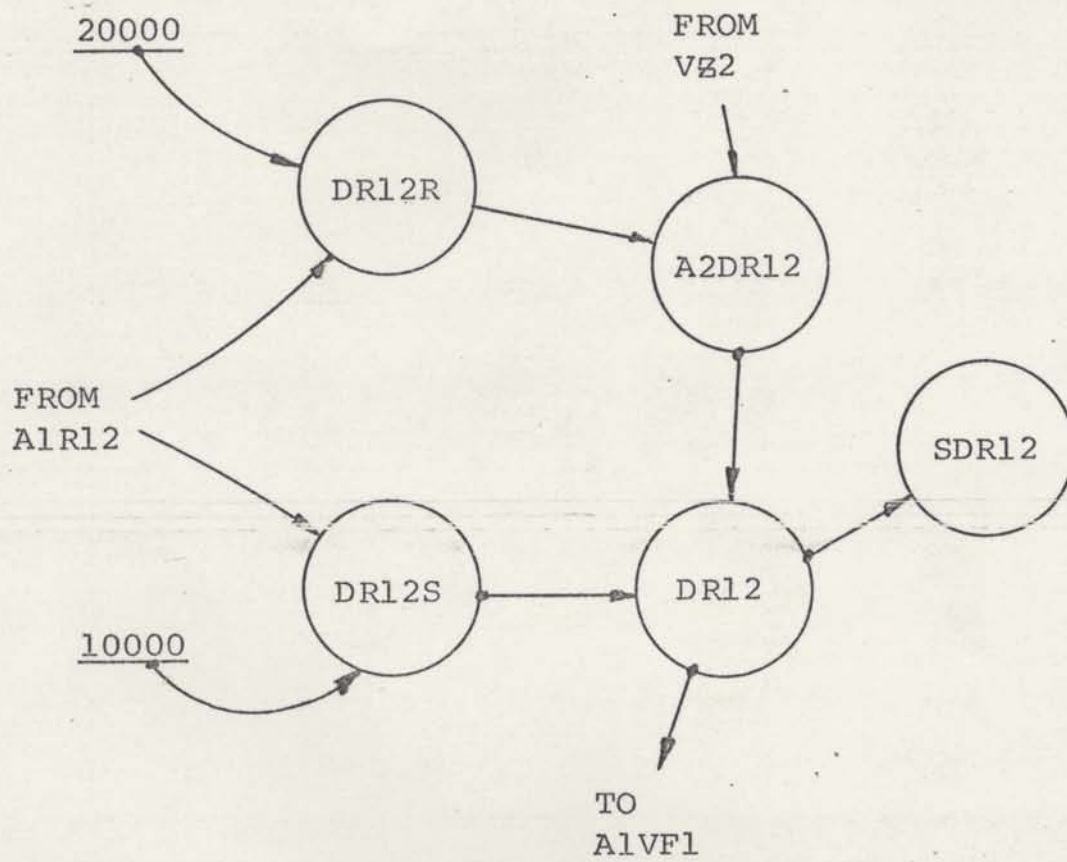


FIGURE 9

yards, DR12R. Sonar contact with the submarine is made when the range is within 10,000 yards, DR12S.

The function DR12 indicates whether the submarine is acquired by either the radar, sonar, or both. The detection function is then smoothed.

Attack and Damage

The attack and damage assessment phase flow diagram is shown in Figure 10. Once the submarine is detected by either or both of the sensors, speed of the destroyer is increased to VMAX and the heading is changed to close the submarine.

If the submarine is being detected by either sensor, A1VF1, and if the range to the submarine is not greater than 5,000 yards, A2VF1, four weapons are fired, WFRV1, one every two minutes until all weapons are expended, A7VF1. The weapon fire rate, WFRV1, is determined by the auxiliary, A5FV1.

For each weapon fired, the noise function is used to determine whether a hit was scored. A 50 percent hit probability is established by setting the threshold of A6VF1 at 0. The damage is assessed based on the number of hits recorded. The speed of the submarine is reduced

ATTACK AND DAMAGE FLOW DIAGRAM

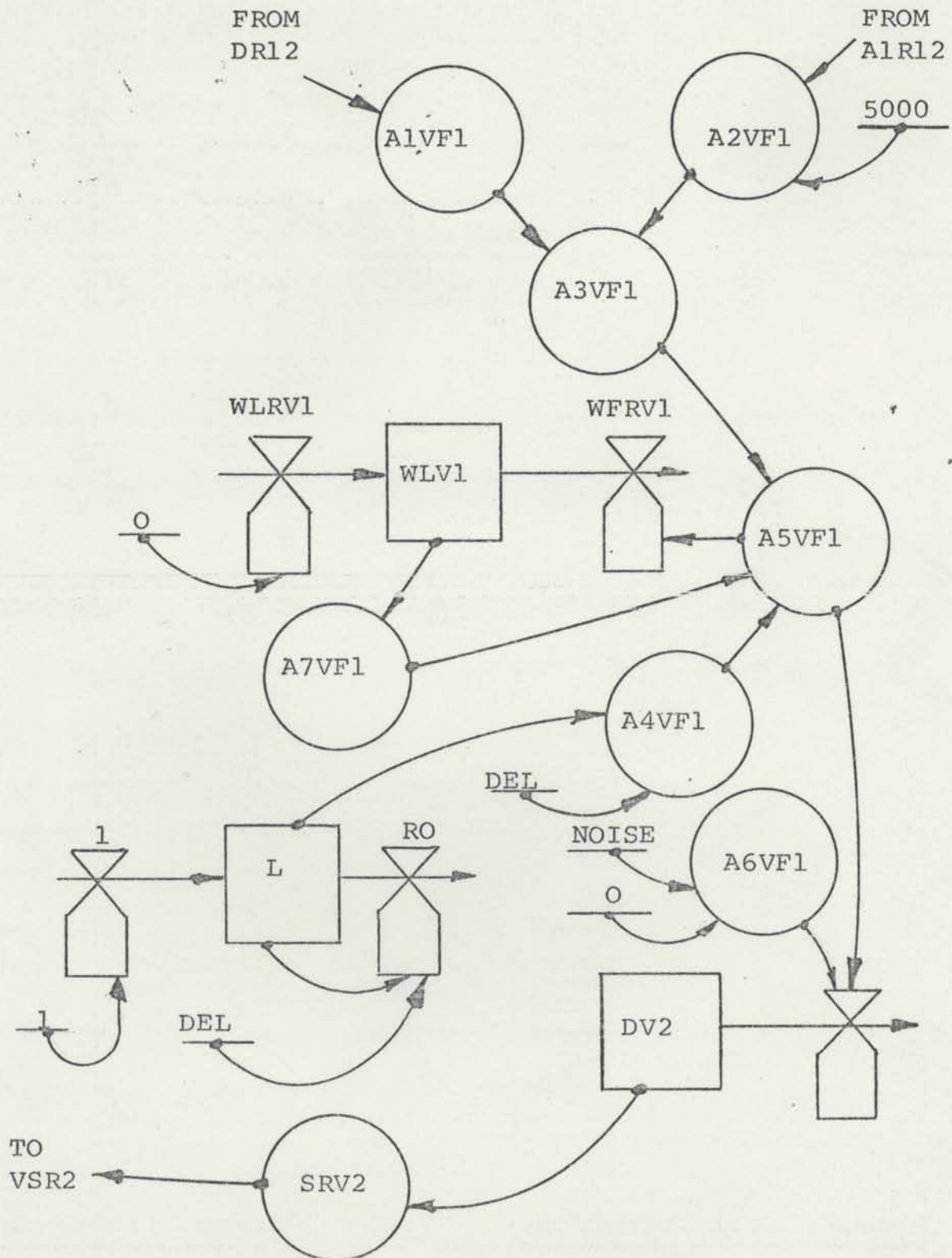


FIGURE 10

based on the speed-correction function shown in Figure 11.

An overall flow diagram for this simple destroyer-versus-submarine problem is shown in Figure 12. In the full context of a war-game model the number of vehicles involved in the game would be expanded. The sensor-detection model and attack-and-damage-assessment models would be expanded based on given or estimated system performance. A logistics or supply replenishment model would be added. A complete war-game model would also include the typical delays which occur in the receipt of information and the response to orders.

Gains would be introduced into the system based on the decisions which are made. The entire model and flow diagram can be prepared in the language of the user.

SPEED CORRECTION FUNCTION

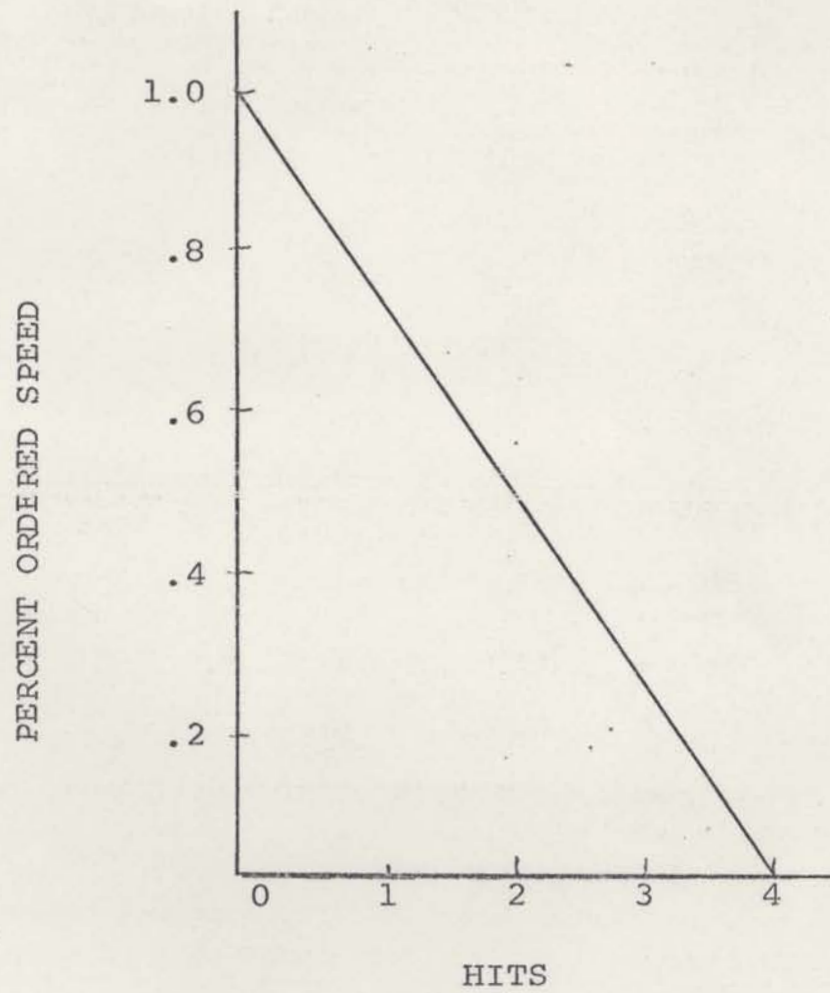


FIGURE 11

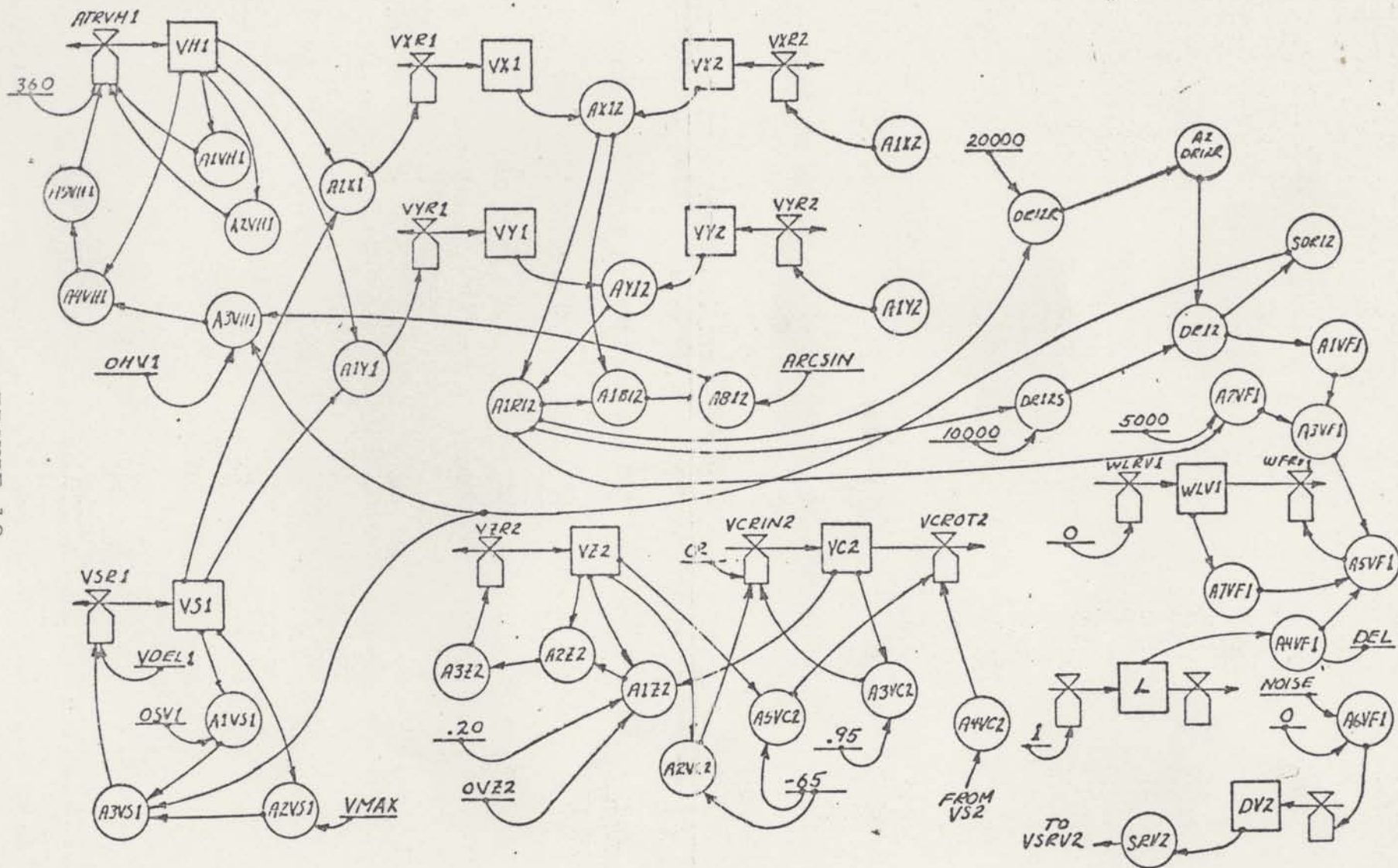


FIGURE 12

CHAPTER VI

COMPUTER PROGRAMS AND PRINTOUTS

The destroyer-versus-submarine war-game model described in Chapter V was programmed in the Dynamo II language (reference 18). The source program listing is provided in Figure 13.

In order to insure a stable computation of the vehicle dynamics portion of the model, a DT of one tenth of a minute was used. The problem was run for 120 minutes or two hours. This problem time was adequate to exercise the basic elements which had been included in the model.

Both a print and a plot requirement were included in the program. The print and plot time interval was established at one minute.

The print and plot results are shown in Appendix A. The plot results demonstrate the well-behaved nature of the model.

The CPU time requirement for program execution was slightly in excess of 11 seconds for two hours of problem time. The processing time of a multivehicle problem soon approaches the limit of medium and even large-scale computing systems.

* SYSTEM DYNAMICS TECHNIQUES FOR WAR GAMING

* DESTROYER VS SUBMARINE

*

NOTE VEHICLE MOTION

NOTE VEHICLE HEADING

L	$VH1.K = VH1.J + (DT) (TRVH1.JK)$	HEADING V1
R	$TRVH1.KL = ATRVH1.K$	TURN RATE
A	$ATTRVH1.K = (360) (A1VH1.K) - (360) (A2VH1.K) + A5VH1.K$	TURN AUX.
A	$A1VH1.K = FIFGE(0.1, VH1.K, 0)$	LOWER LIMIT
A	$A2VH1.K = FIFGE(1.0, VH1.K, 360)$	UPPER LIMIT
A	$A3VH1.K = FIFGE(AR12.K, OHV1.K, SDR12.K, .4)$	COURSE SELECT
A	$A4VH1.K = A3VH1.K - VH1.K$	COURSE ERROR
A	$A5VH1.K = TABHL(TRATE, A4VH1.K, -18, 18, 18)$	TURN RATE
T	$TRATE = -180, 0, 180$	RATE TABLE
A	$OHV1.K = SAMPLE(OH1.K, 30, 90)$	ORDERED HEADING
A	$OH1.K = TABLE(HEAD, TIME.K, 0, 120, 30)$	
T	$HEAD = 90, 30, 80, 0, 20$	TABLE
N	$VH1 = 90$	INITIAL CONDITION
L	$VH2.K = VH2.J + (DT) (TRVH2.JK)$	HEADING V2
R	$TRVH2.KL = 0$	TURN RATE
N	$VH2 = 150$	INITIAL CONDITION

NOTE VEHICLE SPEED

L	$VS1.K = VS1.J + (DT) (VSR1.JK)$	SPEED V1
R	$VSR1.KL = A3VS1.K / VDEL1$	ACCELERATION
A	$A1VS1.K = OSV1.K - VS1.K$	SPEED ERROR
A	$A2VS1.K = VMAX1 - VS1.K$	SPEED ERROR
A	$A3VS1.K = FIFGE(A2VS1.K, A1VS1.K, SDR12.K, 1)$	SPEED SELECT
A	$OSV1.K = SAMPLE(OS.K, 30, 700)$	ORDERED SPEED
A	$OS.K = TABLE(SPEED, TIME.K, 0, 120, 30)$	TABLE
T	$SPEED = 700, 900, 600, 800, 700$	TABLE
N	$VS1 = 700$	INITIAL CONDITION
C	$VMAX1 = 950$	ATTACK SPEED
C	$VDEL1 = 5$	SPEED DELAY
L	$VS2.K = VS2.J + (DT) (VSR2.JK)$	SPEED V2
R	$VSR2.KL = (VS2.K - (350) (SRV2.K)) / 5$	ACCELERATION
N	$VS2 = 350$	INITIAL CONDITION

NOTE VEHICLE DEPTH (SUBMARINE)

L	$VZ2.K = VZ2.J + (DT) (VZR2.JK)$	DEPTH
R	$VZR2.KL = A3Z2.K$	DEPTH RATE
A	$A1Z2.K = FIFGE(OVZ2, -60, VC2.K, .20)$	DEPTH SELECTION
A	$A2Z2.K = A1Z2.K - VZ2.K$	DEPTH ERROR
A	$A3Z2.K = TABHL(DRATE, A2Z2.K, -10, 10, 10)$	DEPTH RATE
T	$DRATE = -10, 0, 10$	TABLE
C	$OVZ2 = -100$	INITIAL CONDITION
N	$VZ2 = -60$	INITIAL CONDITION

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FIGURE 13

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NOTE BATTERY CHARGE

L	VC2.K=VC2.J+(DT)(VCRIN2.JK-VCROT2.JK)	BATTERY CHARGE
R	VCRIN2.KL=(CHR)(A2VC2.K)(A3VC2.K)/60	DISCHARGE RATE
R	VCPOT2.KL=(A4VC2.K)(A5VC2.K)/60	DEPTH SWITCH
A	A2VC2.K=FIFGE(1.0,V72.K,-65)	DEPTH SWITCH
A	A3VC2.K=FIFGE(0.1,VC2.K,.95)	CHARGE LIMIT
A	A4VC2.K=TARHL(DISR,VS2.K,0.600,100)	DISCHARGE VS SPEED
T	DISR=.10,.12,.14,.19,.26,.33,.41	TABLE
A	A5VC2.K=FIFGE(0.1,V72.K,-65)	DEPTH SWITCH
C	CHR=.1	CHARGE RATE
N	VC2=.23	INITIAL CONDITION

*

NOTE RELATIVE POSITION

*

NOTE VEHICLE POSITION

L	VX1.K=VX1.J+(DT)(VXR1.JK)	X1 POSITION
R	VXR1.KL=A1X1.K	X1 RATE
L	VY1.K=VY1.J+(DT)(VYR1.JK)	Y1 POSITION
R	VYR1.KL=A1Y1.K	Y1 RATE
N	VX1=20000	INITIAL CONDITION
N	VY1=20000	INITIAL CONDITION
L	VX2.K=VX2.J+(DT)(VXR2.JK)	X2 POSITION
R	VXR2.KL=A1X2.K	X2 RATE
L	VY2.K=VY2.J+(DT)(VYR2.JK)	Y2 POSITION
R	VYR2.KL=A1Y2.K	Y2 RATE
A	A1X1.K=(VS1.K)(SIN(VH1.K/57.3))	
A	A1Y1.K=(VS1.K)(COS(VH1.K/57.3))	
A	A1X2.K=(VS2.K)(SIN(VH2.K/57.3))	
A	A1Y2.K=(VS2.K)(COS(VH2.K/57.3))	
N	VX2=50000	INITIAL CONDITION
N	VY2=80000	INITIAL CONDITION

*

NOTE RELATIVE POSITION

A	AX12.K=VX2.K-VX1.K	DELTA X
A	AY12.K=VY2.K-VY1.K	DELTA Y
A	A1R12.K=SQRT((AX12.K)(AX12.K)+(AY12.K)(AY12.K))	RANGE
A	A1B12.K=AX12.K/A1R12.K	ARCSIN X/R
A	A2B12.K=TARHL(ARCSIN,A1B12.K,0.1,.05)	TRUE BEARING
A	A3B12.K=FIFGE(1.0,AX12.K,0)	BEARING AUX.
A	A4B12.K=FIFGE(1.0,AY12.K,0)	BEARING AUX.
A	A5B12.K=A3B12.K-A4B12.K	BEARING AUX.
A	A6B12.K=FIFZE(1,-1,A5B12.K)	BEARING AUX.
A	A7B12.K=FIFGE(0.1,AY12.K,0)	BEARING AUX.
A	A8B12.K=FIFGE(0.1,AX12.K,0)	BEARING AUX.
A	A10B12.K=FIFGE(1.0,A11B12.K,2)	BEARING AUX.
A	A11B12.K=A4B12.K+A8B12.K	BEARING AUX.
A	A13B12.K=FIFGE(A1B12.K,-A1R12.K,A1912.K,0)	BEARING AUX.
A	AR12.K=(A6B12.K)(A2B12.K)+(180)(A7B12.K)+(360)(A10B12.K)	BEARING
T	ARCSIN=0.2.9.5.8.8.6.11.6.14.5.17.4.20.5.23.6.24.2.30.0.33.4.	
X	36.9.40.6.44.4.49.1.53.1.58.3.64.2.71.8.90.0	

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NOTE TARGET DETECTION
A DR12R.K=FIFGE(1.0,20000,A1R12.K) RADAR RANGE
A A2DR12R.K=FIFGE(1.0,V72.K,-60) SURFACED SWITCH
A A3DR12R.K=(DR12R.K)(A2DR12R.K) RADAR DETECTION
A DR12S.K=FIFGE(1.0,10000,A1R12.K) SONAR DETECTION
A DR12.K=A3DR12R.K+DR12S.K DETECTION AUX.
A SDR12.K=SMOOTH(DR12.K,10) SMOOTHED DET. AUX.
*
NOTE ATTACK
L WLV1.K=WLV1.J+(DT)((WLRV1.JK/DT)-(WFRV1.JK/DT)) WEAPON LOAD
R WLRV1.KL=0 LOAD RATE
R WFRV1.KL=A5VF1.K FIRE RATE
A A1VF1.K=FIFGE(1.0,DR12.K,1) FIRE CONDITION
A A2VF1.K=FIFGE(0.1,A1R12.K,5000) FIRE CONDITION
A A3VF1.K=(A1VF1.K)(A2VF1.K) FIRE RANGE
A A5VF1.K=(A3VF1.K)(A4VF1.K)(A7VF1.K) FIRE RATE
A A7VF1.K=FIFGE(1.0,WLV1.K,1) WEAPON AUX.
L L.K=L.J+(DT)(1-RO.JK) FIRE RATE AUX.
R RO.KL=FIFGE(DEL/DT,0,L.K,DEL-DT) FIRE RATE AUX.
A A4VF1.K=FIFGE(1.0,L.K,DEL-DT) FIRE RATE AUX.
N WLV1=4 INITIAL CONDITION
N L=0 INITIAL CONDITION
C DFL=2 CONSTANT
*
NOTE DAMAGE
L DV2.K=DV2.J+((DT)(HRV2.JK))/DT DAMAGE
R HRV2.KL=(A5VF1.K)(A6VF1.K) DAMAGE RATE
A A6VF1.K=FIFGE(0.1,NOISE(),0) HIT PROBABILITY
N DV2=0 INITIAL CONDITION
A SRV2.K=TARHL(SRED,DV2.K,0.4,1) TABLE
T SRED=1,.75,.5,.25,0 TABLE
*
*
PRINT VH1,VS1,VX1,VY1,VS2,VX2,VY2,V72,VC2,A1R12,A812,DR12,WLV1,DV2
PLOT VH1=D,VH2=S,A812=R,V72=Z/VX1=1,VY1=2,VX2=3,VY2=4,A1R12=R/VC2=C
PLOT VX1=1,VY1=2,VX2=3,VY2=4,A1R12=R/A812=B
PLOT VH1=D,VH2=S,V72=Z,VC2=C
PLOT WLV1=W,A5VF1=F,DV2=D,A6VF1=P
SPEC DT=.1,LENGTH=120,PRTPER=1,PLTPER=1
RUN

```


As the number of vehicles (n) and sensors per vehicle (s) are increased, the following relationship impacts the size of the program and the run time:

1. Vehicle Motion - $f(n)$
2. Relative Position - $f \left[(n)(n-1)/2 \right]$
3. Sensor - $f \left[(s)(n)(n-1)/2 \right]$
4. Attack and Damage - $f(n)$

Thus, major multivehicle problems soon tax the memory and time capacity of a given computing system. Variable step size (DT) and model simplification are usually traded off against the number of vehicles to optimize the system.

CHAPTER VII

CONCLUSIONS

The development of war gaming for both training and operations research applications has basically emphasized the Monte Carlo aspects of the game. The literature indicates that combat has also been viewed as a time-varying, continuous system which can be expressed as a set of differential equations.

Although modern war-gaming simulations and training equipments consider the dynamics and probabilistic aspects of the system, there is little evidence that combat is viewed as a closed-loop information feedback system. There is also evidence that there is a communication problem between the analyst/programmer and the user in the development of war-game models.

The system dynamics technique which was used in the simplified destroyer-versus-submarine model demonstrated that the word description and the flow diagrams could be developed in the language of the user without becoming deeply involved in the mathematics of the system. This initial phase of the process also has the advantage of forcing an orderly consideration of those elements of combat that are either forgotten, ignored, or simplified

when developing a model. In particular, the identification of delays and gains which are inherent in a particular system can have a significant effect on the characteristics of the system.

The translation of the flow diagrams into the Dynamo II source program was straightforward. The Dynamo print and plot routines produced meaningful information to study the characteristics of the model. Recognizing that the Dynamo language was not developed with a war-game application in mind, there is a certain amount of inefficiency in the statement of logical functions. This deficiency is offset by the power of the language in implementing the other function.

Another weakness of the Dynamo language is the lack of an on-line interactive capability. As a result of this limitation, the introduction of orders or decisions into the scenario must be planned in advance. It is also recognized that a Continuous System Model Programming type language would also be very effective.

In summary it is concluded that the system dynamics techniques can be a powerful tool in the development of

war-game models. Application of these techniques should support the argument that combat is a dynamic system, and more specifically, a closed-loop information feedback system. High-level languages, such as Dynamo and CSMP, should be further developed to improve their logic function capabilities. The development of a user-oriented, high-level language that would have interactive capabilities in faster than real time would be extremely beneficial for training purposes.

APPENDIX 1

DYNAMO PRINT AND PLOT OUTPUTS

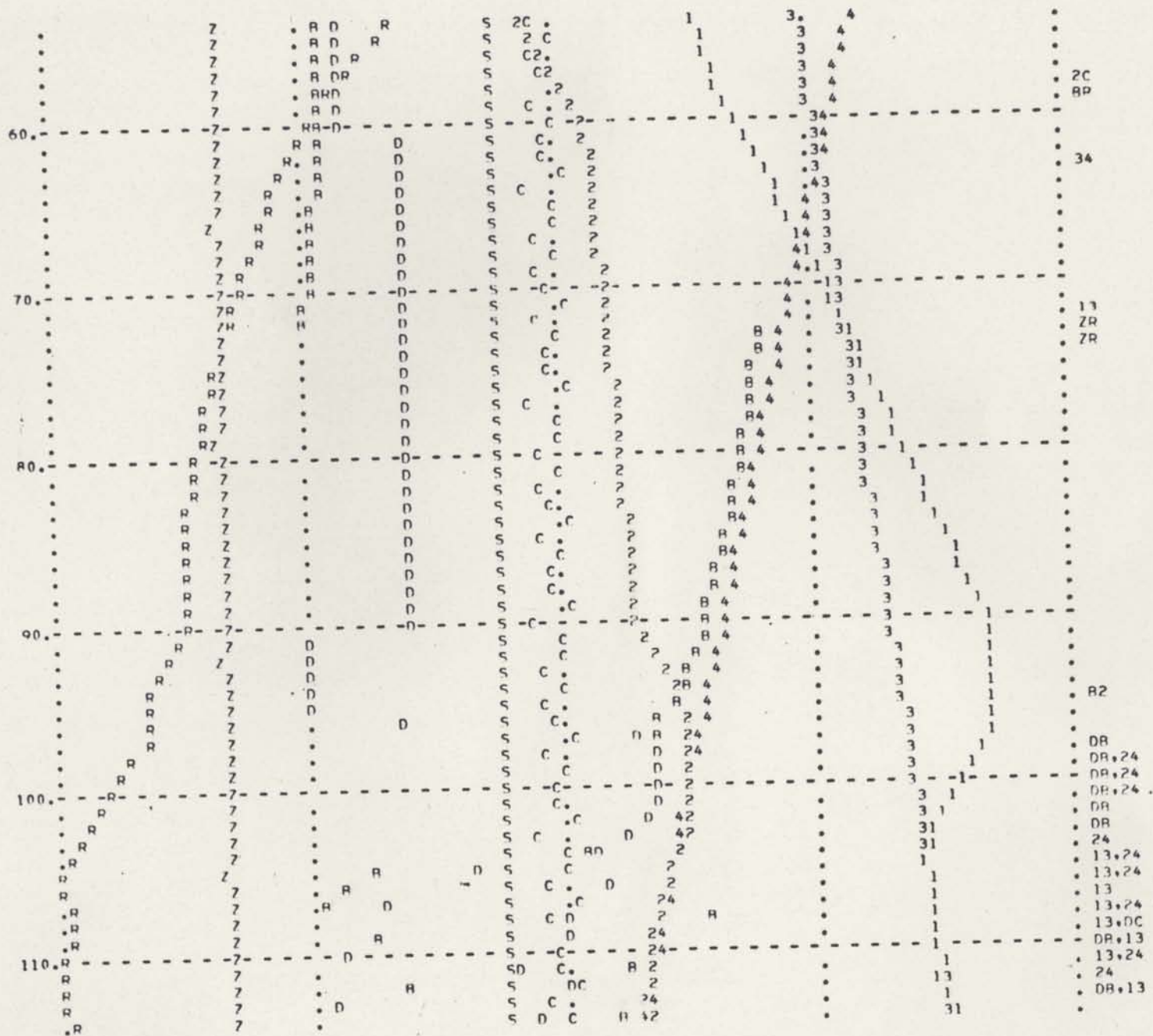
TIME	VH1	VS1	VX1	VY1	VS2	VX2	VY2	VZ2	VC2	AIR12	AR12	DR12	WLVI	DV2
F+00	F+00	F+00	E+03	F+03	F+00	E+03	F+03	E+00	F+00	F+03	F+00	F+00	E+00	E+00
.0	90.00	700.00	20.000	20.000	350.00	50.000	80.000	-60.000	.23000	67.082	24.17	.0000	4.0000	.0000
1.	90.00	700.00	20.700	20.000	350.00	50.175	79.697	-70.000	.22950	66.577	24.11	.0000	4.0000	.0000
2.	90.00	700.00	21.400	20.000	350.00	50.350	79.394	-80.000	.22575	66.074	24.06	.0000	4.0000	.0000
3.	90.00	700.00	22.100	20.000	350.00	50.525	79.091	-90.000	.22200	65.572	24.00	.0000	4.0000	.0000
4.	90.00	700.00	22.800	20.000	350.00	50.700	78.788	-96.513	.21825	65.072	23.95	.0000	4.0000	.0000
5.	90.00	700.00	23.500	20.000	350.00	50.875	78.484	-98.784	.21450	64.574	23.89	.0000	4.0000	.0000
6.	90.00	700.00	24.200	20.000	350.00	51.050	78.181	-99.576	.21075	64.078	23.83	.0000	4.0000	.0000
7.	90.00	700.00	24.900	20.001	350.00	51.225	77.878	-99.852	.20700	63.583	23.77	.0000	4.0000	.0000
8.	90.00	700.00	25.600	20.001	350.00	51.400	77.575	-99.948	.20325	63.091	23.71	.0000	4.0000	.0000
9.	90.00	700.00	26.300	20.001	350.00	51.575	77.272	-98.980	.19950	62.601	23.65	.0000	4.0000	.0000
10.	90.00	700.00	27.000	20.001	350.00	51.750	76.969	-88.980	.19575	62.112	23.51	.0000	4.0000	.0000
11.	90.00	700.00	27.700	20.001	350.00	51.925	76.666	-78.980	.19200	61.626	23.17	.0000	4.0000	.0000
12.	90.00	700.00	28.400	20.001	350.00	52.100	76.363	-68.982	.18825	61.142	22.83	.0000	4.0000	.0000
13.	90.00	700.00	29.099	20.001	350.00	52.276	76.059	-63.132	.18666	60.660	22.49	.0000	4.0000	.0000
14.	90.00	700.00	29.799	20.001	350.00	52.451	75.756	-61.092	.18833	60.181	22.14	.0000	4.0000	.0000
15.	90.00	700.00	30.499	20.001	350.00	52.626	75.453	-60.381	.19000	59.703	21.78	.0000	4.0000	.0000
16.	90.00	700.00	31.199	20.001	350.00	52.801	75.150	-60.133	.19166	59.228	21.41	.0000	4.0000	.0000
17.	90.00	700.00	31.899	20.001	350.00	52.976	74.847	-60.046	.19333	58.756	21.04	.0000	4.0000	.0000
18.	90.00	700.00	32.599	20.001	350.00	53.151	74.544	-60.016	.19500	58.286	20.66	.0000	4.0000	.0000
19.	90.00	700.00	33.299	20.001	350.00	53.326	74.241	-60.006	.19666	57.818	20.27	.0000	4.0000	.0000
20.	90.00	700.00	33.999	20.002	350.00	53.501	73.938	-60.002	.19833	57.353	19.88	.0000	4.0000	.0000
21.	90.00	700.00	34.699	20.002	350.00	53.676	73.634	-60.001	.19999	56.891	19.48	.0000	4.0000	.0000
22.	90.00	700.00	35.399	20.002	350.00	53.851	73.331	-67.200	.19949	56.431	19.07	.0000	4.0000	.0000
23.	90.00	700.00	36.099	20.002	350.00	54.026	73.028	-62.511	.19899	55.975	18.66	.0000	4.0000	.0000
24.	90.00	700.00	36.799	20.002	350.00	54.201	72.725	-64.201	.20066	55.521	18.23	.0000	4.0000	.0000
25.	90.00	700.00	37.499	20.002	350.00	54.376	72.422	-64.358	.19799	55.070	17.80	.0000	4.0000	.0000
26.	90.00	700.00	38.199	20.002	350.00	54.551	72.119	-61.520	.19966	54.622	17.36	.0000	4.0000	.0000
27.	90.00	700.00	38.899	20.002	350.00	54.726	71.816	-68.108	.19970	54.177	16.94	.0000	4.0000	.0000
28.	90.00	700.00	39.599	20.002	350.00	54.901	71.513	-62.827	.19866	53.735	16.52	.0000	4.0000	.0000
29.	90.00	700.00	40.299	20.002	350.00	55.076	71.209	-62.095	.20033	53.297	16.08	.0000	4.0000	.0000
30.	90.00	700.00	40.999	20.002	350.00	55.251	70.906	-65.311	.19820	52.861	15.64	.0000	4.0000	.0000
31.	30.00	736.58	41.452	20.500	350.00	55.426	70.603	-61.852	.19933	52.016	15.58	.0000	4.0000	.0000
32.	30.00	766.47	41.827	21.150	350.00	55.601	70.300	-66.093	.20045	51.044	15.65	.0000	4.0000	.0000
33.	30.00	790.90	42.216	21.823	350.00	55.776	69.957	-63.484	.19833	50.046	15.72	.0000	4.0000	.0000
34.	30.00	810.85	42.616	22.516	350.00	55.951	69.694	-61.215	.19999	49.026	15.78	.0000	4.0000	.0000
35.	30.00	827.16	43.026	23.225	350.00	56.126	69.391	-66.555	.19895	47.988	15.83	.0000	4.0000	.0000
36.	30.00	840.48	43.442	23.947	350.00	56.301	69.088	-62.286	.19899	46.936	15.89	.0000	4.0000	.0000
37.	30.00	851.36	43.865	24.679	350.00	56.476	68.784	-64.093	.20066	45.873	15.95	.0000	4.0000	.0000
38.	30.00	860.26	44.293	25.420	350.00	56.651	68.481	-64.301	.19799	44.800	16.00	.0000	4.0000	.0000
39.	30.00	867.53	44.725	26.168	350.00	56.827	68.178	-61.500	.19966	43.719	16.06	.0000	4.0000	.0000
40.	30.00	873.46	45.160	26.922	350.00	57.002	67.875	-68.093	.19970	42.631	16.11	.0000	4.0000	.0000
41.	30.00	878.31	45.598	27.680	350.00	57.177	67.572	-62.822	.19866	41.538	16.17	.0000	4.0000	.0000
42.	30.00	882.28	46.038	28.442	350.00	57.352	67.269	-62.093	.20032	40.441	16.23	.0000	4.0000	.0000
43.	30.00	885.52	46.480	29.208	350.00	57.527	66.966	-65.310	.19820	39.341	16.29	.0000	4.0000	.0000
44.	30.00	888.16	46.923	29.975	350.00	57.702	66.663	-61.851	.19932	38.238	16.35	.0000	4.0000	.0000
45.	30.00	890.33	47.368	30.745	350.00	57.877	66.359	-66.093	.20045	37.132	16.42	.0000	4.0000	.0000
46.	30.00	892.09	47.813	31.517	350.00	58.052	66.056	-63.484	.19832	36.025	16.48	.0000	4.0000	.0000
47.	30.00	893.54	48.260	32.290	350.00	58.227	65.753	-61.215	.19999	34.916	16.56	.0000	4.0000	.0000
48.	30.00	894.72	48.707	33.065	350.00	58.402	65.450	-66.555	.19895	33.806	16.63	.0000	4.0000	.0000
49.	30.00	895.68	49.154	33.840	350.00	58.577	65.147	-62.286	.19899	32.694	16.72	.0000	4.0000	.0000
50.	30.00	896.47	49.602	34.616	350.00	58.752	64.844	-64.093	.20066	31.583	16.80	.0000	4.0000	.0000
51.	30.00	897.11	50.050	35.392	350.00	58.927	64.541	-64.301	.19799	30.470	16.90	.0000	4.0000	.0000
52.	30.00	897.64	50.499	36.169	350.00	59.102	64.238	-61.500	.19966	29.357	17.00	.0000	4.0000	.0000
53.	30.00	898.06	50.948	36.947	350.00	59.277	63.935	-68.093	.19970	28.244	17.10	.0000	4.0000	.0000
54.	30.00	898.42	51.397	37.725	350.00	59.452	63.632	-62.822	.19866	27.130	17.22	.0000	4.0000	.0000
55.	30.00	898.70	51.846	38.503	350.00	59.627	63.328	-62.093	.20032	26.016	17.35	.0000	4.0000	.0000

TIME	VH1	VS1	VX1	VY1	VS2	VX2	VY2	VZ2	VC2	41R12	4R12	DR12	WLVI	DV2
56.	30.00	898.94	52.296	39.281	350.00	59.802	63.025	-65.310	.19820	24.902	17.49	.0000	4.0000	.0000
57.	30.00	899.13	52.745	40.060	350.00	59.977	62.722	-61.851	.19932	23.788	17.65	.0000	4.0000	.0000
58.	30.00	899.29	53.195	40.839	350.00	60.152	62.419	-66.093	.20045	22.674	17.82	.0000	4.0000	.0000
59.	30.00	899.41	53.645	41.617	350.00	60.327	62.116	-63.484	.19832	21.560	18.02	.0000	4.0000	.0000
60.	30.00	899.52	54.094	42.396	350.00	60.502	61.813	-61.215	.19999	20.447	18.23	.0000	4.0000	.0000
61.	79.00	844.73	54.883	42.676	350.00	60.677	61.510	-66.555	.19895	19.705	17.05	.0000	4.0000	.0000
62.	79.00	799.97	55.695	42.819	350.00	60.852	61.207	-62.286	.19899	19.098	15.66	.0000	4.0000	.0000
63.	79.00	763.40	56.466	42.955	350.00	61.027	60.904	-64.093	.20065	18.520	14.29	.0000	4.0000	.0000
64.	79.00	733.52	57.204	43.085	350.00	61.203	60.601	-64.301	.19799	17.966	12.91	.0000	4.0000	.0000
65.	79.00	709.10	57.915	43.211	350.00	61.378	60.298	-61.500	.19965	17.434	11.52	.0000	4.0000	.0000
66.	79.00	689.15	58.604	43.332	350.00	61.553	59.994	-68.093	.19969	16.921	10.06	.0000	4.0000	.0000
67.	79.00	672.85	59.275	43.451	350.00	61.728	59.691	-62.822	.19865	16.425	8.56	.0000	4.0000	.0000
68.	79.00	659.53	59.931	43.567	350.00	61.903	59.388	-62.093	.20032	15.944	7.12	.0000	4.0000	.0000
69.	79.00	648.64	60.576	43.680	350.00	62.078	59.085	-65.310	.19819	15.478	5.63	.0000	4.0000	.0000
69.99	79.00	639.75	61.211	43.793	350.00	62.253	58.782	-61.851	.19932	15.026	4.02	.0000	4.0000	.0000
70.99	79.00	632.49	61.837	43.903	350.00	62.428	58.479	-66.093	.20044	14.588	2.35	.0000	4.0000	.0000
71.99	79.00	626.55	62.457	44.013	350.00	62.603	58.176	-63.484	.19832	14.164	.60	.0000	4.0000	.0000
72.99	79.00	621.70	63.072	44.121	350.00	62.778	57.873	-61.215	.19999	13.755	358.76	.0000	4.0000	.0000
73.99	79.00	617.74	63.682	44.229	350.00	62.953	57.570	-66.555	.19894	13.361	356.83	.0000	4.0000	.0000
74.99	79.00	614.50	64.289	44.336	350.00	63.128	57.267	-62.286	.19898	12.983	354.81	.0000	4.0000	.0000
75.99	79.00	611.85	64.893	44.443	350.00	63.303	56.964	-64.093	.20065	12.622	352.74	.0000	4.0000	.0000
76.99	79.00	609.69	65.495	44.549	350.00	63.478	56.661	-64.301	.19798	12.278	350.54	.0000	4.0000	.0000
77.99	79.00	607.93	66.094	44.655	350.00	63.653	56.357	-61.500	.19965	11.955	348.16	.0000	4.0000	.0000
78.99	79.00	606.48	66.692	44.760	350.00	63.828	56.054	-68.093	.19969	11.652	345.74	.0000	4.0000	.0000
79.99	79.00	605.30	67.288	44.866	350.00	64.003	55.751	-62.822	.19865	11.371	343.24	.0000	4.0000	.0000
80.99	79.00	604.34	67.883	44.971	350.00	64.178	55.448	-62.093	.20032	11.113	340.53	.0000	4.0000	.0000
81.99	79.00	603.55	68.478	45.076	350.00	64.353	55.145	-65.310	.19819	10.881	337.70	.0000	4.0000	.0000
82.99	79.00	602.91	69.072	45.181	350.00	64.528	54.842	-61.851	.19932	10.676	336.09	.0000	4.0000	.0000
83.99	79.00	602.38	69.665	45.285	350.00	64.703	54.539	-66.093	.20044	10.500	333.19	.0000	4.0000	.0000
84.99	79.00	601.95	70.257	45.390	350.00	64.878	54.236	-63.484	.19832	10.353	328.67	.0000	4.0000	.0000
85.99	79.00	601.60	70.850	45.495	350.00	65.053	53.933	-61.215	.19998	10.237	325.46	.0000	4.0000	.0000
86.99	79.00	601.32	71.442	45.599	350.00	65.228	53.630	-66.555	.19894	10.154	322.22	.0000	4.0000	.0000
87.99	79.00	601.08	72.034	45.704	350.00	65.403	53.327	-62.286	.19898	10.103	318.92	.0000	4.0000	.0000
88.99	79.00	600.89	72.625	45.808	350.00	65.578	53.023	-64.093	.20065	10.085	315.70	.0000	4.0000	.0000
89.99	79.00	600.73	73.216	45.913	350.00	65.753	52.720	-64.301	.19798	10.102	311.95	.0000	4.0000	.0000
90.99	.02	637.18	73.406	46.425	350.00	65.928	52.417	-61.500	.19965	9.583	308.47	1.0000	4.0000	.0000
91.99	.02	666.95	73.406	47.076	350.00	66.103	52.114	-68.093	.19969	8.872	304.50	1.0000	4.0000	.0000
92.99	.02	691.28	73.406	47.754	350.00	66.278	51.811	-62.822	.19865	8.202	299.45	1.0000	4.0000	.0000
93.99	.02	711.16	73.406	48.455	350.00	66.453	51.508	-62.093	.20031	7.594	293.43	1.0000	4.0000	.0000
94.99	.02	727.40	73.406	49.173	350.00	66.628	51.205	-65.310	.19819	7.076	285.33	1.0000	4.0000	.0000
95.99	72.02	740.67	73.532	49.859	350.00	66.803	50.902	-61.851	.19931	6.809	274.30	1.0000	4.0000	.0000
96.99	252.02	751.52	73.746	49.433	350.00	66.978	50.599	-66.093	.20044	6.868	275.28	1.0000	4.0000	.0000
97.99	273.87	760.37	72.996	49.459	350.00	67.153	50.296	-63.484	.19831	5.902	273.67	1.0000	4.0000	.0000
98.99	272.00	767.61	72.233	49.499	350.00	67.328	49.993	-61.215	.19998	4.930	271.83	1.0000	4.0000	.0000
99.99	270.44	773.53	71.463	49.516	350.00	67.503	49.690	-66.555	.19894	3.963	270.35	1.0000	4.0000	.0000
100.99	269.81	778.36	70.687	49.517	350.00	67.678	49.386	-62.286	.19898	3.011	269.66	1.0000	3.0000	.0000
101.99	264.29	782.31	69.907	49.492	350.00	67.853	49.083	-64.093	.20065	2.094	262.99	1.0000	3.0000	.0000
102.99	246.77	785.54	69.148	49.309	350.00	68.028	48.780	-64.301	.19798	1.238	244.87	1.0000	2.0000	.0000
103.99	220.27	788.17	68.495	48.881	350.00	68.203	48.477	-61.500	.19965	.498	215.83	1.0000	2.0000	.0000
104.99	126.47	790.33	68.365	48.169	335.45	68.375	48.179	-68.093	.19973	.015	47.30	1.0000	1.0000	1.0000
105.99	234.47	792.09	68.424	47.623	322.11	68.540	47.894	-62.822	.19879	.295	23.17	1.0000	1.0000	1.0000
106.99	54.47	793.52	68.650	47.170	311.20	68.698	47.620	-63.215	.20045	.453	6.11	1.0000	.0000	1.0000
107.99	198.47	794.70	69.190	47.057	302.29	68.851	47.354	-64.851	.19820	.451	310.76	1.0000	.0000	1.0000
108.99	198.47	795.66	68.554	46.739	295.01	69.000	47.095	-61.691	.19986	.570	51.65	1.0000	.0000	1.0000
109.99	22.16	796.44	69.006	46.505	289.06	69.146	46.842	-66.903	.19915	.365	22.65	1.0000	.0000	1.0000
110.99	163.92	797.08	69.554	46.709	284.20	69.289	46.594	-62.407	.19892	.289	246.84	1.0000	.0000	1.0000
111.99	199.92	797.61	69.083	46.220	280.23	69.430	46.349	-64.151	.20059	.370	69.93	1.0000	.0000	1.0000

TIME	VH1	VS1	VX1	VY1	VS2	VX2	VY2	VZ2	VC2	ALR12	AR12	DR12	WL11	DV2
112.99	19.92	798.04	69.530	45.974	276.99	69.569	46.103	-64.332	.19853	.139	16.51	1.0000	.0000	1.0000
113.99	178.51	798.39	70.060	46.062	274.34	69.707	45.869	-62.678	.20020	.403	241.53	1.0000	.0000	1.0000
114.99	192.34	798.67	69.523	45.600	272.17	69.843	45.632	-65.694	.19864	.322	88.17	1.0000	.0000	1.0000
115.99	12.34	798.91	69.999	45.414	270.40	69.979	45.397	-61.985	.19939	.026	229.94	1.0000	.0000	1.0000
116.99	192.34	799.10	70.508	45.384	268.95	70.113	45.164	-67.302	.20014	.452	240.99	1.0000	.0000	1.0000
117.99	151.79	799.25	70.086	44.799	267.77	70.247	44.931	-63.216	.19906	.209	50.93	1.0000	.0000	1.0000
118.99	187.79	799.38	70.672	44.392	266.81	70.381	44.700	-65.709	.20073	.424	316.59	1.0000	.0000	1.0000
119.99	187.79	799.48	70.103	43.960	266.02	70.514	44.469	-64.166	.19829	.654	38.93	1.0000	.0000	1.0000

$VH1=0, VH2=5, AR12=R, VZ2=Z, VX1=1, VY1=2, VX2=3, VY2=4, A1R12=R, VC2=C$

[illegible]



R	Z	.	SD	C	2	B	.	1	. 13,24
R	Z	.	S	C	0		.	13	. 24
R	Z	.	S	C	2		.	1	. 13
R	Z	.	S	C	2		.	31	. 24
R	Z	.	S	C	4		.	1	. 13,24
R	Z	.	S	C	2		.	1	. SR,13,24

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